Interacting New Agegraphic Dark Energy in a Cyclic Universe

K. Saaidi[*,†1] • **H. Sheikhahmadi**[* 2] •
A. H. Mohammadi[** 3]

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Abstract The main goal of this work is investigation of NADE in the cyclic universe scenario. Since, cyclic universe is explained by a phantom phase ($\omega < -1$), it is shown when there is no interaction between matter and dark energy, ADE and NADE do not produce a phantom phase, then can not describe cyclic universe. Therefore, we study interacting models of ADE and NADE in the modified Friedmann equation. We find out that, in the high energy regime, which it is a necessary part of cyclic universe evolution, only NADE can describe this phantom phase era for cyclic universe. Considering deceleration parameter tells us that the universe has a deceleration phase after an acceleration phase, and NADE is able to produce a cyclic universe. Also it is found valuable to study generalized second law of thermodynamics. Since the loop quantum correction is taken account in high energy regime, it may not be suitable to use standard treatment of thermodynamics, so we turn our attention to the result of (Li et al. 2009), which the authors have studied thermodynamics in loop quantum gravity, and we show that which condition can satisfy generalized second law of thermodynamics.

Keywords Cyclic universe; Low energy Regime; High Energy Regime; Agegraphich Dark Energy.

K. Saaidi[*,†]

H. Sheikhahmadi[*]

A. H. Mohammadi[**]

[*]Department of Physics, Faculty of Science, University of Kurdistan, Sanandaj, Iran.

[†]Department of Physics, Kansas State University,116 Cardwell Hall, Manhattan, KS 66506, USA.

[**]Islamic Azad University, Evaz Branch, Fars Province, Iran

[1]ksaaidi@phys.ksu.edu

[2]h.sh.ahmadi@uok.ac.ir

[3]abolhassanm@gmail.com

1 Introduction

Cosmological and astronomical observations such as supernovae type Ia observational data (Perlmuter et al. 1997; Reiss et al. 1998; de Bernardis, et al. 2000) and Wilkonson Microwave Anisotropic Probe (WMAP) (Astier et al. 2006; Perlmutter et al. 1999; Peiris et al. 2003; Riess et al. 2007) imply that the universe is undergoing a period of accelerated expansion. Since normal matter can not give rise to accelerated expansion of the universe, Scientists came up with a solution which expresses that this expansion is a result of an ambiguous fluid named Dark Energy (Bridle et al. 2003; Koght et al. 2003).

The theoretical and experimental analysis suggest that the universe consist of %73 dark energy, %23 cold dark matter (CDM), and remnant matter is baryons (Fujii and Maeda 2003; Spergel et al. 2003). Unfortunately the nature and origin of dark energy are ambiguous up to now, but people have proposed some candidates to describe dark energy. Amongst the various candidates of dark energy to describe accelerated expansion of the universe, cosmological constant (vacuum energy), Λ, with equation of state (EoS) $\omega = -1$ is located in central position. However, as it is well known, the cosmological constant proposal has two famous problems, fine-tuning problem and the cosmic coincidence problem (Weinberg 1989; Steinhardt 1997; Carroll 2001; Peebles and Ratra 2003). Some other of dark energy models suggest that dark energy component can treat as scalar field with dynamical EoS. In this scenario the evolution of the field is very slow, so that kinetic energy density is less than the potential energy density, and this give us a negative pressure, responsible to the cosmic acceleration (Frieman et al. 1995; Turner and White 1997; Caldwell et al. 1998). Some of scalar field models are as chameleon field (Khoury et al. 2004;

Mota and Barrow 2004), quintessence (Q-field) (Liddle, et al. 1999; Peebles and Ratra 1999), and phantom. In the phantom field scenario, the parameter of EoS is as $\omega < -1$, due to existence of a negative kinetic energy density of scalar field. It is well known that the phantom dark energy model suffers from two kind of problems, "Big Bang" singularity and "Big Rip" singularity, where big bang is related to initial epoch of universe and big rip is related to a finite future singularity. Since the space-time singularities are invidious for theorists, models that avoid these singularities are attractive. One of these models names cyclic universe which have received huge attention (Brown et al. 2008; Baum and Frampton 2007; Brown et al. 2008). Presence of ρ^2 term with a negative sign in Friedmann equation (which is used at studying cyclic universe) is an effective way to eliminate these singularities. In the cyclic universe scenario, where is based on the phantom dark energy model, the universe oscillates through a series of expansion and contraction. Universe in this scenario has a very high energy density at beginning an ending of the expansion, so quantum gravity can not be ignored in these stages (Ashtekar. 2006b,a). This evolution can be result from the modified Friedmann equation in the loop quantum cosmology (LQC). In LQC, the Friedmann equation has been modified to

$$H^2 = \frac{\rho}{3m_p^2}\left(1 - \frac{\rho}{\rho_c}\right), \tag{1}$$

where H is the Hubble parameter, m_p^2 is the reduced planck mass ($m_p^2 = \frac{1}{8\pi G} = 2.44 \times 10^{18} GeV$), ρ is the total of energy density, ρ_c is the critical energy density as $\rho_c = 4\sqrt{3}\gamma^{-3}m_p^4 = 0.82\rho_p$, where $\rho_p = 2.22 \times 10^{76} GeV$, and γ is the dimensionless Barbero-Immirizi parameter (Ashtekar et al. 2006c). We notice, this correction can solve the singularity problems as follow, when the total energy density reaches the critical density, the universe reaches the maximum at the end of expansion that is called "turnaround point", and universe arrives at smallest size at the end of contraction, then we have a bounce there (Boyle, et al. 2004; Khoury et al. 2001; Steinhardt and Turok 2002; Boyle, et al. 2006). We emphasize the idea of cyclic universe was first introduced by Tolman (Tolman 1931, 1934).

An interesting attempt for probing the nature of dark energy, in the framework of quantum gravity, is the holographic dark energy (HDE). In the HDE model, dark energy is a dynamical evolving vacuum energy density that can satisfy the phantom behavior. Authors of (Zhang et al. 2007) have investigated the cyclic universe by HDE (and some interesting work about HDE have been done (Li 2004; Setare et al. 2007a,b; Karami and Fehri 2010; Cohen et al. 1999; Enqvist and Sloth 2004; Dutta et al. 2010). Another attractive model to describe the nature of dark energy, within the framework of a fundamental theory originating from some considerations of the feature of quantum gravity theory, is called agegraphic dark energy (ADE) model (Cai 2007). The ADE assumes that the dark energy comes from the universe components fluctuation such as space-time and matter fluctuation (for further discussion we refer the reader to (Kim et al. 2008; Nozri and Azizi 2009; Kim 2008; Karami et al 2008; Setare 2010). In this model, the age of universe is taken as the length measure instead of the horizon distance, therefore the causality problem which appears in the HDE model can be avoided. The ADE model suffers from the difficulty to describe the matter dominant epoch. The authors of (Wei et al. 2008) have introduced a new mechanism to overcome that problem, which it is called new agegraphic dark energy (NADE) model, and its energy density is defined by $\rho_\Lambda = 3n^2 m_p^2 \eta^{-2}$, where $3n^2$ is introduced to parameterized some uncertainties and η is conformal time and can be written as

$$\eta = \int_0^a \frac{da}{a^2 H}, \tag{2}$$

where a is scale factor and H is well-known as Hubble parameter. Cyclic model of universe, due to avoiding singularity, and NADE, due to estimating a good approximate of dark energy value and solving causality problem of HDE, have received huge interest. In previous works, like (Wei et al. 2008), it was only mentioned that interaction NADE can produce phantom, however it was not explained that if NADE can produce cyclic universe and how the quantities like dark energy density parameter, equation of state parameter, and deceleration parameter behave in cyclic universe by taking NADE as component of dark energy. In this work we motivated to take NADE as dark energy and investigate universe evolution in cyclic model. If it is able to stand in phantom area, it may produce cyclic universe, however it is not all of story. Although, presence of this type of dark energy displays an accelerated universe, but the most important thing in cyclic universe is that, after a while, the universe should enter in a deceleration area and recontract in turnaround point.

2 High and low energy

In this step, we focus on high energy regime. Certainly the quadratic term of energy density in the Friedmann equation can not be ignored, this term can play a very

impressive role in the evolution of universe. The modified Friedmann equation is as

$$3H^2 = \rho \left(1 - \frac{\rho}{\rho_c} \right), \tag{3}$$

where ρ is a combination of dark energy density, ρ_Λ, and matter density, ρ_m. For dark energy dominant in high energy regime, the above relation can be rewritten as

$$3H^2 \approx \rho_\Lambda \left(1 - \frac{\rho_\Lambda}{\rho_c} \right), \tag{4}$$

so, according to this relation the parameter of dark energy may be estimated as

$$\Omega_\Lambda^\natural = \frac{\rho_\Lambda}{3H^2} \approx \frac{\rho_c}{\rho_c - \rho_\Lambda}. \tag{5}$$

$\Omega_\Lambda^\natural$ is always larger than one, and it can be very large when the universe approaches to the turnaround point. However note that, since we have ρ_m, although it is very small, $\Omega_\Lambda^\natural$ can not be infinite. This small value of ρ_m does not allow ρ_Λ to reach the exact value of ρ_c, then the presence of ρ_m can prevent the infinite value of $\Omega_\Lambda^\natural$.

If we assume there is no interaction between these two components of the universe, conservation equation can be written as

$$\begin{aligned}
\dot{\rho}_m + 3H(1+\omega_m)\rho_m &= 0 \\
\dot{\rho}_\Lambda + 3H(1+\omega_\Lambda)\rho_\Lambda &= 0.
\end{aligned} \tag{6}$$

By taking ADE, which is defined as $\rho_\Lambda = 3n^2 T^{-2}$ where T denotes time, as dark energy component of universe, ω_Λ is obtained as

$$\omega_\Lambda = -1 + \frac{2}{3n} \sqrt{\Omega_\Lambda^\natural}. \tag{7}$$

Also, if we replace NADE instead of ADE, we arrive at same result but only scale factor, a, should be added in the denominator of second term on the right hand of relation (7). Since the latest term, in both case, is always positive ω_Λ never can be smaller than -1. Since phantom type of dark energy is requisite for cyclic universe (phantom energy density is getting larger with increasing scale factor so the total energy density reaches the critical energy density in turnaround point and universe begins contraction), selecting ADE and NADE, without interaction, as a component of dark energy in cyclic universe is not suitable (Wei et al. 2008).

Assumption of interaction between ρ_m and ρ_Λ may solve above problem. By including interaction, the conservation equations are as

$$\begin{aligned}
\dot{\rho}_m + 3H(1+\omega_m)\rho_m &= Q \tag{8} \\
\dot{\rho}_\Lambda + 3H(1+\omega_\Lambda)\rho_\Lambda &= -Q, \tag{9}
\end{aligned}$$

where Q indicates interaction. Q is taken as $Q = \Gamma \rho_\Lambda$, with $\Gamma > 0$, which means there is transfer of energy from ρ_Λ to ρ_m Sheykhi et al. (2010). We take Q as $Q = 3b^2 H(1+r)\rho_\Lambda$, where $r = \frac{\rho_m}{\rho_\Lambda}$. Setting ADE as the component of dark energy gives us an ω_Λ as

$$\omega_\Lambda = -1 + \frac{2}{3n} \sqrt{\Omega_\Lambda^\natural} - b^2(1+r). \tag{10}$$

$\Omega_\Lambda^\natural$ is always larger than one, and it becomes very large at turnaround point, so for having $\omega_\Lambda < -1$, we should have $b^2(1+r) > \frac{2\sqrt{\Omega_\Lambda^\natural}}{3n}$. This predicts a large value for coupling constant b, while it is in contrast to the obtained value of another papers such as (Sheykhi et al. 2010).

Now, NADE is taken as ρ_Λ which that is the main case of this work. Because we use conformal time η instead of T, scale factor appear in relation (10), namely

$$\omega_\Lambda = -1 + \frac{2}{3na} \sqrt{\Omega_\Lambda^\natural} - b^2(1+r). \tag{11}$$

To have $\omega_\Lambda < -1$, the coupling constant b should obey following relation

$$b^2 > \frac{2}{3na} \sqrt{\Omega_\Lambda^\natural}, \tag{12}$$

here, r has been ignored because of $\rho_m \ll \rho_\Lambda$. If $\Omega_\Lambda^\natural$ be in order of a^2, we may obtain a convenient value for b in order it could give us phantom dark energy in this regime.

In Fig.1 ω_Λ parameter has been plotted versus $r = \frac{\rho_m}{\rho_\Lambda}$, for three different value of interaction coupling constant. In expansion phase, by passing time, the quantity r decreases and makes ω_Λ larger. Since it still stands in phantom range, larger value of ω_Λ shows that dark energy density grows up slower; in contrast to the contraction phase. Also, having stronger interaction coupling causes smaller value for ω_Λ.

If $\Omega_\Lambda^\natural$ be in order of a^ξ, where $\xi \leq 2$, equation (12) can be valid in good approximation. Now suppose $\Omega_\Lambda^\natural$ is in order of a^2, for instance $\Omega_\Lambda^\natural = \alpha a^2$. From equation (12) we have $b^2 > \frac{2\sqrt{\alpha}}{3n}$, and by taking the value of (Sheykhi et al. 2010) for b, namely $b^2 = 0.25$, we
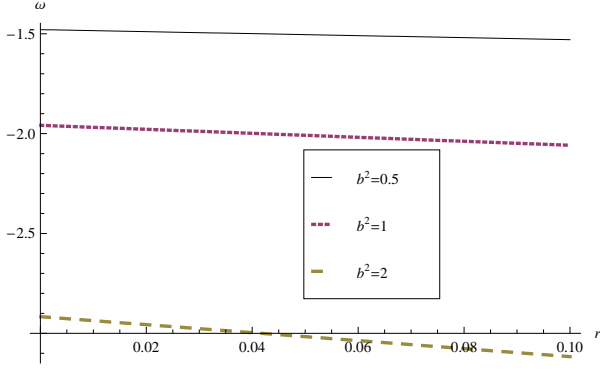
Fig. 1 equation of state parameter of dark energy has been plotted versus the dimensionless quantity $r = \frac{\rho_m}{\rho_\Lambda}$, for three different value of interaction coupling constant.

obtain the value of α as $\sqrt{\alpha} < \frac{3}{8}n$.

Now, we want to obtain differential equation for $\Omega_\Lambda^\natural$. In the NADE, ρ_Λ is given as

$$\rho_\Lambda = \frac{3n^2}{\eta^2}. \tag{13}$$

From the definition of dark energy density parameter, namely $\Omega_\Lambda^\natural = \frac{\rho_\Lambda}{3H^2}$, The differential equation for $\Omega_\Lambda^\natural$ is acquired as

$$\Omega_\Lambda^{\natural\,\prime} = -2\Omega_\Lambda^\natural \left(\frac{\dot{H}}{H^2} + \frac{\sqrt{\Omega_\Lambda^\natural}}{an}, \right) \tag{14}$$

where prime denote derivative with respect to $\mathcal{N} = \ln a$. Taking the time derivative of modified Friedmann equation, and substituting that in the above equation, we obtain

$$\frac{\dot{H}}{H^2} = \frac{-3}{2}\left((1+\omega_m)\Omega_m^\natural + (1+\omega_\Lambda)\Omega_\Lambda^\natural \right)\left(1 - \frac{2\rho}{\rho_c} \right), \tag{15}$$

since, in the high energy regime, $\Omega_m^\natural$ can be ignored against to $\Omega_\Lambda^\natural$, therefore one can estimate

$$\frac{\dot{H}}{H^2} \approx \frac{-3}{2}(1+\omega_\Lambda)\Omega_\Lambda^\natural \left(1 - \frac{2\rho}{\rho_c} \right), \tag{16}$$

(for driving above equation we have used $\frac{H^2}{\rho_c} = \frac{\Omega_\Lambda^\natural - 1}{3\Omega_\Lambda^{\natural\,2}}$, see ref.(Sheykhi et al. 2010). The differential equa-

tion, which governs the NADE evolution of universe in high energy regime, can be attained as

$$\Omega_\Lambda^{\natural\,\prime} = -2\Omega_\Lambda^\natural \left\{ \frac{\sqrt{\Omega_\Lambda^\natural}}{na}(\Omega_\Lambda^\natural - 1) - 3b^2(1+r)(\frac{1}{2}\Omega_\Lambda^\natural - 1) \right\} \tag{17}$$

with attention to (12), it is clearly shown that $\Omega_\Lambda^{\natural\,\prime} = \frac{1}{H}\dot{\Omega}_\Lambda^\natural$ is positive. So one can realize that when the universe is growing up (decreasing) $\dot{\Omega}_\Lambda^\natural$ is positive (negative) which it displays that dark energy density parameter is increasing (decreasing) by passing time. By passing the universe from turnaround point, $\Omega_\Lambda^\natural$ decreases and puts the universe in low energy regime.
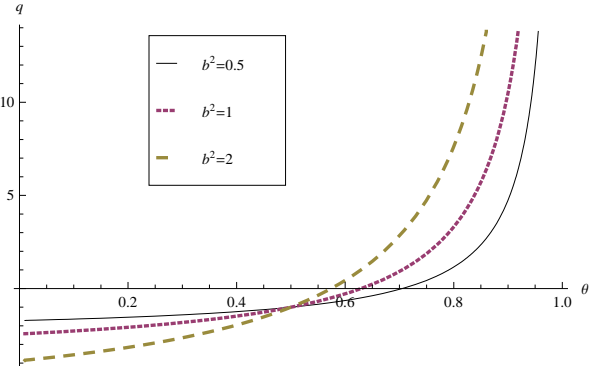
Another useful cosmological parameter is deceleration parameter which can tell us if the expansion of universe is accelerating or not. Deceleration parameter is given by
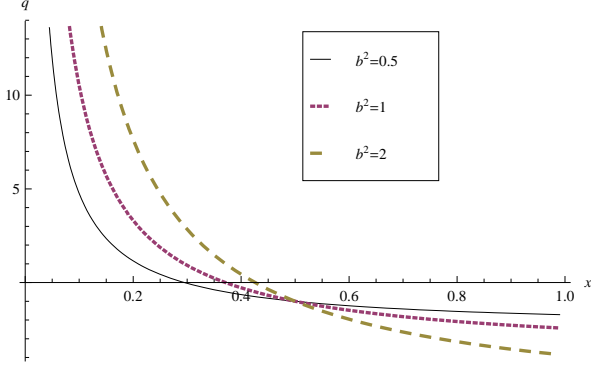
$$q = -1 - \frac{\dot{H}}{H^2}, \tag{18}$$

substituting $\frac{\dot{H}}{H^2}$ term in the above relation, we arrive at

$$\begin{aligned} q &= -1 + \frac{3}{2}\left((1+\omega_m)\Omega_m^\natural + (1+\omega_\Lambda)\Omega_\Lambda^\natural \right) \\ &\quad \times \left(1 - \frac{2\rho}{\rho_c} \right) \\ &= -1 + \frac{3}{2}(1+\omega_\Lambda)\Omega_\Lambda^\natural \left(1 - \frac{2\rho}{\rho_c} \right). \end{aligned} \tag{19}$$

Deceleration parameter has been plotted versus the

Fig. 2 (expansion epoch) Deceleration parameter, q, has been plotted versus the dimensionless quantity $\theta = \frac{\rho_\Lambda}{\rho_c}$, for three different value of interaction coupling constant.

Fig. 3 (contraction epoch) Deceleration parameter, q, has been plotted versus the dimensionless quantity $x = 1 - \theta$, for three different value of interaction coupling constant.

dimensionless quantity $\theta = \frac{\rho_\Lambda}{\rho_c}$ for expansion and contraction epoch of universe evolution in Fig.2. and Fig.3. respectively (with attention to this fact that ω_Λ stands in phantom range). In the plots three different values for b are taken as $b^2 = 0.5, 1, 2$; which displays the strange of interaction between matter and dark energy. Fig.2. shows that q has negative values that it means the universe is in an acceleration phase and getting larger. Since there is a positive value for Hubble parameter, $\Omega_\Lambda^\natural$ increases too. By passing time and increasing dark energy density, q approaches to zero, therefore the universe moves from acceleration phase to deceleration phase. However since we are in expansion epoch of universe evolution, $\Omega_\Lambda^\natural$ is still getting larger which causes q grows rapidly (and as we expect larger values of interaction coupling constant makes q to grow up faster). Reaching energy density to critical energy density, the universe is forced to stop expansion and change its evolution direction and start to contract in turnaround point. In contraction epoch, the universe is getting smaller more and more with a large value of q at the beginning of contraction, as it has been shown in Fig.3. The Hubble parameter has negative values and $\Omega_\Lambda^\natural$ decreases therefore dark energy density is diluted. q again takes negative values, however the universe continue to contract and decrease more and more, until it moves to low energy regime and dark energy dilute enough in which matter and radiation become dominant.

Up to now, from above discussion in high energy regime, we found out that NADE can satisfy a phantom fluid for cyclic scenario. However this is not at all our universe, there is also regime related to the low energy, where $\rho \ll \rho_c$. At this regime we have the usual Friedmann equation for universe, namely

$$3H^2 = \rho = \rho_m + \rho_\Lambda.$$

By defining the energy density parameters in the form of

$$\Omega_i = \frac{\rho_i}{3H^2}, \tag{20}$$

where i refer to matter and dark energy. One can rearrange the standard Friedmann equation as $1 = \Omega_m + \Omega_\Lambda$, from this relation we find out the maximum value of Ω_i is one. Now, NADE is taken as dark energy component with interaction with matter, so from conservation equation related to the dark energy and with the help of above Friedmann equation, one obtain ω_Λ as

$$\omega_\Lambda = -1 + \frac{2}{3a} \frac{\sqrt{\Omega_\Lambda}}{n} - 3b^2(1+r), \tag{21}$$

maximum value of dark energy density parameter, namely Ω_Λ is one and also when the scale factor is large enough to make the second term on the right hand of above relation small in which ω_Λ stands in phantom range. The sort of dark energy as a component of universe fluid has been determined, so we want to be aware about the evolution of universe in this stage. The deceleration parameter is expressed as

$$q = -1 + \frac{3}{2}\Big((1+\omega_m)\Omega_m + (1+\omega_\Lambda)\Omega_\Lambda\Big), \tag{22}$$

so in the earlier time when Ω_Λ converge to zero (and Ω_m converge to one) the deceleration parameter is as $q \approx 1$ for $\omega_m = \frac{1}{3}$, and $q \approx \frac{1}{2}$ for $\omega_m = 0$ that indicates a deceleration universe. Whereas in the late time when Ω_Λ approaches to one , the deceleration parameter has negative sign that introduces an acceleration universe.

3 Validity of second law of thermodynamics

So far, we investigated whether NADE can produce a phantom dark energy for cyclic universe. Now, it can be valuable to study validity of generalized second law of thermodynamic in the model and consider which condition can satisfy generalized second law. Since loop quantum gravity correction enters in Friedmann equation which plays an important role in the evolution of universe, especially in high energy regime, it is not suitable one straightforward extends the standard treatment of thermodynamic. For this reason we use the result of (Li et al. 2009) which thermodynamic has been investigated in loop quantum cosmology there. The authors of (Li et al. 2009) have performed their work by

taking a dynamical apparent horizon as universe horizon. It has been demonstrated that one can have

$$dE = TdS + WdV. \tag{23}$$

However note that, here $E = \rho_{eff}V = \rho\left(1 - \frac{\rho}{\rho_c}\right)V$ which ρ_{eff} is effective energy density and $W = \frac{1}{2}(\rho_{eff} - P_{eff})$ (in which $P_{eff} = P\left(1 - \frac{2\rho}{\rho_c}\right) - \frac{\rho^2}{\rho_c^2}$ is effective pressure). The relation can be very useful in this step of the work. Like (Li et al. 2009), we take apparent horizon

$$R_A = \frac{1}{H}.$$

From considering the validity of generalized second law, we should sum variation of entropy for both of horizon and fluid inside the horizon. The horizon entropy

$$\dot{S}_h = 2\pi R_A \dot{R}_A \tag{24}$$

For the relation (23), the entropy variation of fluid inside the horizon can be acquired as

$$T_I \dot{S}_I = V\dot{\rho}_{eff} + \frac{(\rho_{eff} + P_{eff})}{2}\dot{V} \tag{25}$$

Note that, there is an equilibrium between the temperature of horizon and matter inside the horizon. Using modified Friedmann equation and conservation relations and also with the help of the definition of horizon and energy density parameters, the total entropy variation is resulted as

$$\begin{aligned}
\dot{S}_{tot} &= 3\pi\Big((1+\omega_m)\Omega_m + (1+\omega_\Lambda)\Omega_\Lambda^\natural\Big)\left(1 - \frac{2\rho}{\rho_c}\right) \\
&\quad \left\{R_A + \frac{3}{T_I}\Big((1+\omega_m)\Omega_m + (1+\omega_\Lambda)\Omega_\Lambda\Big) \right. \\
&\quad \left. \times\left(1 - \frac{2\rho}{\rho_c}\right) - \frac{4}{T_I}\right\}
\end{aligned} \tag{26}$$

Now, we turn our attention to the high energy regime where Ω_m can be ignored against to the large value of $\Omega_\Lambda^\natural$. Define $\alpha = \frac{\rho}{\rho_c}$ in which $0 < \alpha < 1$, then the total entropy variation is reorganized as

$$\begin{aligned}
\dot{S}_{tot} &= 3\pi(1+\omega_\Lambda)(1-2\alpha)\Omega_\Lambda^\natural \\
&\quad \times\left\{R_A + \frac{3}{T_I}(1+\omega_\Lambda)(1-2\alpha)\Omega_\Lambda^\natural - \frac{4}{T_I}\right\},
\end{aligned} \tag{27}$$

where $(1+\omega_\Lambda) < 0$. If $\alpha < \frac{1}{2}$, for making valid the second law, there should be

$$R_A < -\frac{3(1+\omega_\Lambda)(1-2\alpha)}{T_I}\Omega_\Lambda^\natural.$$

However, if $\alpha > \frac{1}{2}$, the total entropy variation is always positive.

In low energy density, $\Omega_\Lambda^\natural$ tends to Ω_Λ where $0 < \Omega_\Lambda < 1$, also α approaches to zero, so one arrives at

$$\dot{S}_{tot} = 3\pi\beta\left(R_A + \frac{3\beta}{T_I} - \frac{4}{T_I}\right) \tag{28}$$

where $\beta = \Big((1+\omega_m)\Omega_m + (1+\omega_\Lambda)\Omega_\Lambda\Big)$. In radiation and matter dominant, where Ω_Λ converges to zero, β is positive and we should have

$$T_I > \frac{4 - 3\beta}{R_A}$$

to generalized second law be valid. In radiation and matter dominant ω_m is equal to $\frac{1}{3}$ and 0 respectively. This expresses that the right term is positive. Passing time, the dark energy eventually dominates and Ω_Λ increases to one, so $\beta < 0$. The generalized second law leads us to the below condition for temperature

$$T_I \leq \frac{4 - 3\beta}{R_A}$$

and since β is negative we can have a positive value for temperature. So the generalized second law of thermodynamics can be valid, and it can be a confirmation for the model.

4 Conclusion

During this work, in brief, it was shown that both of ADE and NADE, without interaction with matter in both high and low energy regime, can not satisfy phantom dark energy which it is a necessary condition for cyclic universe scenario. So, as it was the main goal of the work, an interaction between the fluid components of the universe was supposed. At first step, we turned our attention to the high energy regime, and we realized that , in ADE case for providing a phantom fluid there must be a large value for coupling constant b which it is not compatible with the results of previous works, but NADE can produce a phantom fluid for cyclic universe while dark energy density parameter, namely $\Omega_\Lambda^\natural$, behaves as a^ξ where $\xi \leq 2$. It was explained that, in expansion phase, equation of state parameter of dark energy increases by decreasing $r = \frac{\rho_m}{\rho_\Lambda}$. However in

contraction phase, the quantity r increases, so ω_Λ decreases. In contraction phase with attention to this fact that dark energy stands in phantom range, smaller values of ω_Λ express that dark energy density decreases faster and let universe to enter matter dominant phase. Moreover larger value of interaction coupling constant produce smaller valus for ω_Λ.

Considering differential equation of $\Omega_\Lambda^\natural$ exhibited that after passing the universe from turnaround point (in contracting phase), $\Omega_\Lambda^\natural$ decreases and after a while the universe is putted in low energy regime, then matter and radiation are be allowed to be dominate. By computing deceleration parameter, it was found out that there is negative values for q which shows that the universe is in an accelerated expansion phase. Increasing dark energy density enters q in positive area and it is made larger. Then, the universe moves from an accelerated expansion phase to a deceleration phase and it is slowing down until it stops expansion and starts contraction in turnaround point. So it is realized that the model is able to create a deceleration phase and start contraction after an accelerated expansion phase. In next step, we investigated the low energy regime of universe where it can be possible to ignore loop quantum correction in Friedmann relation and go back to usual form. Investigation shew us that, in low energy regime, ω_Λ stands in phantom range. Also, considering deceleration parameter displayed that universe expansion decelerates in both of matter and radiation dominant, where Ω_Λ is small enough, and accelerates by increasing Ω_Λ toward one. In the last part of the work, we studied the validity of generalized second law of thermodynamic in both case of high and low energy. In high energy it was determined that when $\alpha = \frac{\rho}{\rho_c} > \frac{1}{2}$ the total entropy variation is always positive. At low energy, we shew that to make valid the law, a bound for temperature is imposed.

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